

Life after eruption – I. Spectroscopic observations of ten nova candidates

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Accepted. Received

ABSTRACT

We have started a project to investigate the connection of post-novae with the population of cataclysmic variables. Our first steps in this concern improving the sample of known post-novae and their properties. Here we present the recovery and/or confirmation of the old novae MT Cen, V812 Cen, V655 CrA, IL Nor, V2109 Oph, V909 Sgr, V2572 Sgr, and V728 Sco. Principal photometric and spectroscopic properties of these systems are discussed. We find that V909 Sgr is a probable magnetic CV, and that V728 Sco is a high-inclination system. We furthermore suggest that the two candidate novae V734 Sco and V1310 Sgr have been misclassified and instead are Mira variables.

Key words: binaries: close – novae, cataclysmic variables – stars: variables: general

1 INTRODUCTION

A nova eruption in a cataclysmic binary star (CV) occurs as a thermonuclear explosion on the surface of the white dwarf primary star once it has accumulated a critical mass from its late-type, usually main-sequence, companion. In the process of the eruption, material is ejected into the interstellar medium. The mass of the shell typically amounts to 10^{-5} to $10^{-4} M_{\odot}$ (e.g., Yaron et al. 2005). There is recent evidence that the mass of the white dwarf increases in the course of the secular evolution of CVs (Zorotovic, Schreiber, & Gänsicke 2011). Consequently, in nova eruptions less than the accumulated mass is ejected. With typical mass-transfer rates of a few 10^{-8} to $10^{-9} M_{\odot} \text{ yr}^{-1}$ (Townsend & Gänsicke 2009) the typical recurrence time of a nova eruption $> 10^3$ yr. This distinguishes the classical novae from the recurrent novae that have much shorter recurrence times in the order of decades, and in most cases have a giant donor.

In between nova eruptions the binary is supposed to appear as a “normal” CV, i.e. its behaviour is dominated by its current mass-transfer rate and the magnetic field strength of the white dwarf (Vogt 1989). Furthermore, the hibernation model predicts that most of the time between eruptions the system passes as a detached binary (Shara et al. 1986; Prialnik & Shara 1986). The proposed scenario here is that the binary separation increases due to the mass lost from the white dwarf during the eruption. The primary is heated by the thermonuclear runaway, thus in return heats the companion star,

driving it far out of thermal equilibrium, and so sustaining a high mass-transfer rate in spite of the increased separation. The mass-transfer rate gradually decreases and eventually the donor can relax to thermal equilibrium, losing contact to its Roche lobe, and the system becomes detached. While there is still no observational evidence for the latter part of this scenario, i.e. the state of actual “hibernation” (e.g., Naylor et al. 1992), it is already well established that old novae are part of the CV class. For example, the system DQ Her (Nova Her 1934) is known as the prototype intermediate polar, while RR Pic (Nova Pic 1925) shows the characteristics of an SW Sex system (Schmidtbreick, Tappert, & Saviane 2003a). GK Per (Nova Per 1901) seems to be an intermediate polar, revealing, decades after its nova eruption, the typical behaviour of a dwarf nova, with semi-periodic outbursts (Šimon 2002). Furthermore, the discovery of a nova shell around the dwarf nova Z Cam (Shara et al. 2007) proves that (at least some) systems discovered as CVs are also old novae.

In spite of these, more or less isolated and exotic, cases, there is still only a fragmentary knowledge of the generally valid long-term behaviour of classical novae before and after their eruption. A study based on 97 relatively well observed galactic novae by Vogt (1990) revealed a decrease in brightness with a mean slope 21 ± 6 mmag per year during the first 130 years after the eruption. Similar results were obtained by Duerbeck (1992) who derived, from a sample of nine very well covered cases, a mean decline rate of 10 ± 3 mmag per year, half a century after outburst. This is all our knowledge, at present.

Most classical novae have orbital periods between 3 and 6 hours (Diaz & Bruch 1997). In this period range we find several other classes of CVs, in particular dwarf novae, magnetic CVs, and

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† Based on observations with ESO telescopes, proposal numbers 083.D-0158, 086.D-0428, and 087.D-0323

nova-like variables like SW Sex and UX UMa stars, most of them characterised by high mass-transfer rates. Do all these CVs suffer nova eruptions? Is the magnetic field of the white dwarf of any importance for the eruption recurrence time? And do post-novae really go into hibernation, i.e. do CVs become detached for a time as a consequence of the nova eruption? We do not know, although answering these questions would be rather important for our understanding of CVs. The only way to progress here would be a more exhaustive investigation of the detailed behaviour of old novae decades and centuries after their outbursts. As a first step towards this goal, it is necessary to identify the remnants of past novae, especially those which had erupted long time ago.

Our knowledge, in this respect, is largely incomplete. There are about 200 confirmed or suspected novae with eruptions before 1980, but for less than half of them a spectrum of the post-nova has been obtained. Only for 39 of these, a value for the orbital period is listed. Moreover, eight of these can be regarded as uncertain since they were obtained photometrically without the light curve presenting definite orbital features like eclipses or ellipsoidal variations, two more (DY Pup and DI Lac) are based on unpublished data (Downes et al. 2005), and the 5.714 d period of V1017 Sgr is marked as “preliminary” (Sekiguchi 1992). This leaves a mere 28 old novae with a well-established orbital period.

To improve the current situation on systematic research on old novae we have started a program to identify nova candidates with *UBVR* photometry via their specific colours and to confirm them with low-resolution spectroscopy (Schmidtobreick et al. 2003b, 2005). For sufficiently bright systems, we furthermore plan to determine their orbital period by measuring radial velocities obtained with time-series spectroscopy. Since our main interest regards the underlying CV we intend to limit our research to novae where the nova shell is already sufficiently faint to provide only a negligible contribution at least to the optical spectrum. The time scale for the fading of the nova shell will be different for individual systems. However, a literature research on well-known novae shows that after about 30 years the nebular lines have disappeared from the spectra in almost all systems¹. In order to facilitate the selection, we therefore limit our study to novae that erupted before 1980.

We here present the results for ten candidate old novae.

2 OBSERVATIONS AND REDUCTION

The data were obtained during three observing runs in May 2009, February and June 2011, at the ESO-NTT, La Silla, Chile, using EFOSC2 (Eckert, Hofstadt, & Melnick 1989). Only during the first run the weather conditions allowed for calibrated photometry. The respective data were taken as ≥ 3 exposures in the *U*, *B*, *V*, and *R* passbands. Between each exposure the telescope was moved slightly so that pixel deficiencies would average out when combining them to a single frame. The individual frames were bias-corrected, but not flatfielded, because EFOSC2 flats suffer significantly from a central light concentration problem. Subsequently, aperture photometry was performed using IRAF’s `phot` package. These served as input for the standalone `daomatch` routine (Stetson 1992) to determine the offsets between the individual frames. Correcting for these offsets, the frames were combined to a

¹ For a counter-example see the nova HR Del that still presents a significant contribution of nebular lines 40 years after the eruption (Friedjung, Dennefeld, & Voloshina 2010)

Table 3. Results of the *UBVR* photometry.

object	<i>V</i>	<i>U</i> − <i>B</i>	<i>B</i> − <i>V</i>	<i>V</i> − <i>R</i>
MT Cen	19.79(12)	−0.04(03)	1.10(02)	0.47(02)
V812 Cen	21.32(15)	−0.57(07)	0.57(06)	0.54(05)
IL Nor	19.03(14)	−0.69(01)	0.29(02)	0.34(02)
V909 Sgr	20.39(14)	−0.49(02)	0.32(02)	0.20(02)
V728 Sco	18.47(13)	−0.83(01)	0.42(01)	0.60(01)

single one using a 3σ clipping algorithm for the averaging. Since all photometric fields are located in crowded regions the stellar magnitudes were determined by fitting the point spread function (PSF). Finally, the magnitudes were calibrated using photometric data of standard stars (Landolt 1983, 1992) that were taken in the same night.

The spectroscopic data were collected using grism 4 and, in one case, grism 11, in combination with a $1.0''$ slit. In another case, the $1.5''$ slit was employed with grism 4. Similar to the photometry, the data consisted of three individual spectra that were later combined prior to the extraction process. The data were corrected for bias, divided by normalised flats, and afterwards combined and extracted using IRAF routines. Wavelength calibration was performed using Helium-Argon lamps. The resulting typical spectral ranges and resolutions are 3490–7470 Å at 13 Å (FWHM, i.e. Full Width at Half Maximum for an arc line) for grism 11, and 4050–7440 Å at 11.5 Å (34 Å in case of the $1.5''$ slit) for grism 4. The spectra were corrected for the instrumental response function using standard star spectra obtained during the May 2009 run for grism 4, and the February 2011 run for grism 11. Since the conditions were not photometric during these nights, these spectra can not be considered as calibrated in absolute flux, but only regarding the relative spectral energy distribution (SED).

In order to determine the coordinates reported in Table 1, we have performed an astrometric correction of the combined *R*-band frames (or, for those objects without calibrated photometry, of the *R*-band acquisition frame) using the routines embedded in Starlink’s GAIA² tool (version 4.4.1) with the UCAC3 (Zacharias et al. 2010) catalogue. Prior to the final fit, saturated stars and ambiguous positions (close visual binaries) were manually deleted. The typical RMS of the fit amounted to significantly less than 1 pixel, i.e. less than $0.24''$.

3 RESULTS

3.1 MT Cen = Nova Cen 1931

MT Cen was classified as a fast nova ($t_3 \sim 10$ d) that reached a photographic brightness of 8.4 mag on May 12, 1931 (Duerbeck 1984). Due to its faintness already the later stages of the eruption are only sparsely covered, and first attempts to observe the post-nova or its shell were unsuccessful (Munari & Zwitter 1998; Gill & O’Brien 1998, respectively). Later, Woudt & Warner (2002) identified a likely candidate for the post-nova by detecting flickering-like variability in their high-speed photometry.

Our colour-colour diagram (Fig. 2, top) points out this same object as having colours different from the majority of the stars in the field. This becomes more pronounced if only the central part of

² <http://astro.dur.ac.uk/~pdraper/gaia/gaia.html>

Table 1. Log of observations.

object	R.A. (2000.0)	DEC (2000.0)	date	filter/grism	t_{exp} [s]	mag ¹
MT Cen	11:44:00.24	−60:33:35.7	2009-05-20	UBVR	1800/900/300/180	19.8 <i>V</i>
			2011-02-16	grism 11, slit 1.0	3600	19.5 <i>R</i>
V812 Cen	13:13:54.32	−57:40:44.4	2009-05-21	UBVR	1800/900/300/180	21.3 <i>V</i>
			2009-05-22	grism 4, slit 1.0	5400	20.0 <i>R</i>
V655 CrA	18:24:44.73	−36:59:41.8	2009-05-23	grism 4, slit 1.5	1080	17.7 <i>R</i>
IL Nor	15:29:23.00	−50:35:00.4	2009-05-21	UBVR	1800/900/300/180	19.0 <i>V</i>
			2011-02-26	grism 4, slit 1.0	1800	18.9 <i>R</i>
V2109 Oph	17:24:16.04	−24:36:50.2	2009-05-24	grism 4, slit 1.0	2700	19.7 <i>R</i>
V909 Sgr	18:25:52.30	−35:01:26.5	2009-05-21	UBVR	1800/900/300/240	20.4 <i>V</i>
			2011-06-29	grism 4, slit 1.0	7200	19.5 <i>R</i>
V1310 Sgr	18:35:01.02	−30:03:35.9	2009-05-23	grism 4, slit 1.5	3600	13.5 <i>R</i>
V2572 Sgr	18:31:36.81	−32:35:58.4	2009-05-24	grism 4, slit 1.0	2700	17.8 <i>R</i>
V728 Sco	17:39:05.58	−45:27:14.4	2009-05-20	UBVR	1800/900/300/180	18.5 <i>V</i>
			2011-06-29	grism 4, slit 1.0	1800	18.2 <i>R</i>
V734 Sco	17:45:02.36	−35:38:07.1	2009-05-19	grism 4, slit 1.0	3600	<13.2 <i>R</i> ²

1) *V* magnitudes were derived from the calibrated EFOSC2 photometry, *R* magnitudes were estimated by comparing our acquisition frames with data from the USNO-A2.0 catalogue (Monet 1998) as implemented in the ESO archive. The typical overall uncertainty is estimated to ~ 0.3 mag (for the *V* magnitudes see Table 3).

2) star is saturated in the acquisition frame

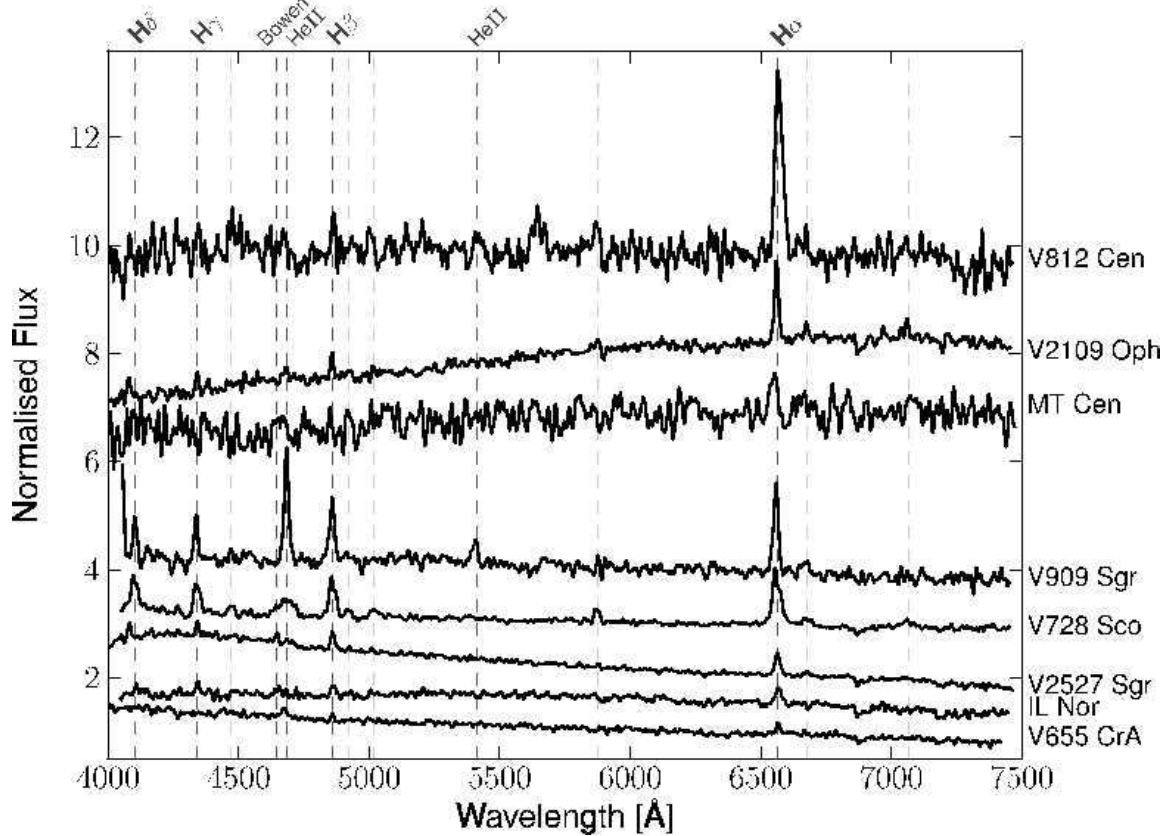


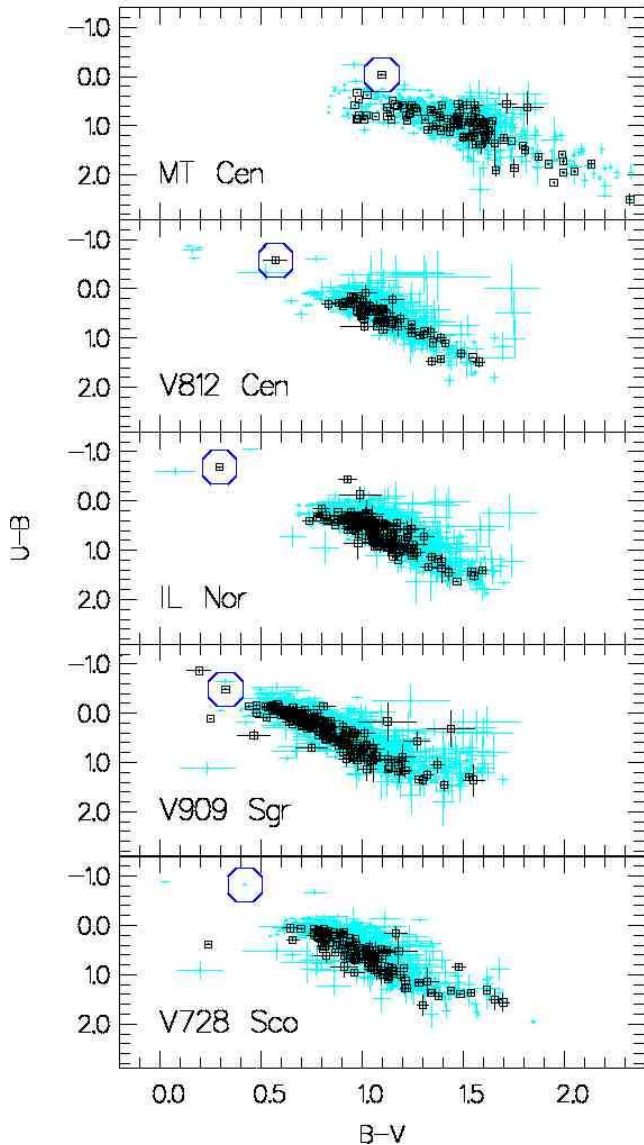
Figure 1. Spectra of the eight confirmed classical novae. The fluxes have been normalised by dividing through the mean value, the spectra have been smoothed by a 3×3 box filter, and they have been shifted vertically for clarity. The positions of Balmer, HeII, and the Bowen emission features are indicated by the dashed, dark grey, lines and labelled at the top of the plot. Unlabelled, light grey, dashed lines mark HeI lines.

Table 2. Equivalent widths (in absolute values of angstroms) of the identified emission lines for the confirmed post-novae. The errors were estimated using a Monte Carlo simulation.

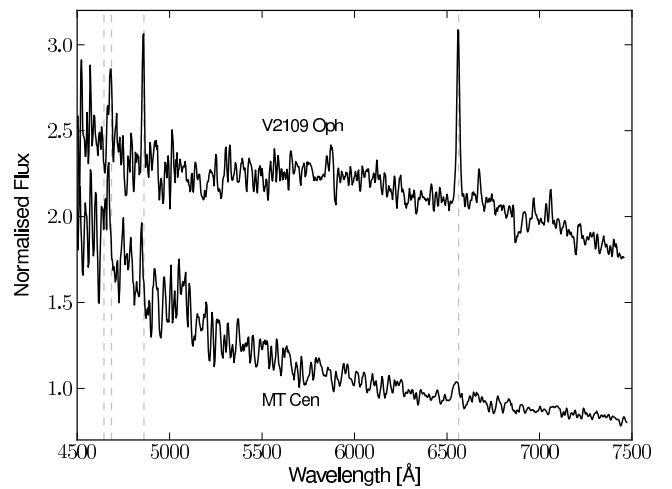
object	Balmer						HeI				Bowen/HeII	HeII
	4101	4340	4861	6563	4472	4922	5016	5876 ¹	6678	7065	4645/4686 ²	5412
MT Cen	–	–	5(2)	15(4)	–	–	–	–	–	–	11(4)	–
V812 Cen	–	–	15(4)	120(12)	–	–	–	16(7)	6(3)	–	–	–
V655 CrA	–	–	1(1)	4(1)	–	–	–	–	–	–	3(1)	–
IL Nor	2(1)	3(1)	4(1)	9(1)	–	–	–	1(1)	–	–	4(1)	–
V2109 Oph	20(8)	14(3)	9(2)	22(1)	–	–	–	5(1)	3(1)	3(1)	7(2)	–
V909 Sgr	10(4)	16(2)	24(2)	39(3)	2(1)	1(1)	–	2(1)	9(2)	–	42(2)	10(2)
V2572 Sgr	3(1)	2(0.5)	4(1)	13(1)	–	1(0.5)	1(0.5)	1(0.5)	2(1)	–	4(1)	–
V728 Sco	12(3)	16(1)	21(1)	40(1)	4(1)	3(2)	6(1)	5(1)	4(1)	8(1)	21(1)	–

1) this line is mostly distorted by the adjacent NaI absorption.

2) our resolution does not permit to properly resolve these components.

**Figure 2.** Colour-colour diagram ($U-B$ vs $B-V$) for the fields of MT Cen, V812 Cen, IL Nor, V909 Sgr, and V728 Sco. The black squares indicate objects within the central 300×300 pixels ($\sim 1.2 \times 1.2'$). The post-nova is marked with a circle.**Table 4.** Galactic coordinates and corresponding interstellar extinction (Schlegel, Finkbeiner, & Davis 1998, taken from NASA's IRSA web interface).

object	l	b	$E(B-V)$ [mag]
MT Cen	294.7	+1.2	1.60
V812 Cen	305.9	+5.1	0.50
V655 CrA	356.9	−11.1	0.12
IL Nor	326.8	+4.8	0.58
V2109 Oph	1.1	+6.3	0.92
V909 Sgr	358.8	−10.4	0.11
V1310 Sgr	4.2	−10.0	0.12
V2572 Sgr	1.5	−10.4	0.15
V728 Sco	345.2	−7.6	0.37
V734 Sco	354.2	−3.4	0.94

**Figure 3.** Dereddened spectra of MT Cen and V2109 Oph, the two novae that are the most strongly affected by extinction (Table 4). Like in Fig. 1, the spectra have been smoothed with a 3×3 box filter, normalised by dividing through the mean value, and displaced vertically for clarity. The dashed vertical lines mark (from left to right) the positions of the Bowen blend, HeII 4686, $H\beta$ and $H\alpha$.

the CCD image is considered (black squares in Fig. 2). Our spectrum of the candidate has very low S/N (Fig. 1), but the detection of weak $H\alpha$ emission confirms the post-nova. In agreement with the not particularly blue colour derived photometrically (Table 3), the continuum flux increases toward longer wavelengths. One possibility is that the late-type donor contributes significantly to the optical flux, which would indicate either a low-mass-transfer system, or a bright donor, the latter implying a long orbital period. However, this part of the sky suffers from considerable reddening (Table 4). In order to examine the influence of the extinction we have dereddened the spectrum using the corresponding IRAF task, which is based on the relations derived by Cardelli, Clayton, & Mathis (1989). Since the absolute extinction $A(V)$ is not known, we have used the standard value for the ratio $R(V) = A(V)/E(B - V) = 3.1$. The resulting dereddened spectrum is shown in Fig. 3. It proves that the red slope of the continuum was entirely due to interstellar reddening, which even masked the presence of the emission components of $H\beta$ and the Bowen blend. The corrected spectrum shows an SED that is typical for a high mass-transfer system.

3.2 V812 Cen = Nova Cen 1973

This object was a late discovery, reported five years after its eruption by MacConnell, Prato, & Briceno (1978) who detected a typical spectrum of a nova in its nebular phase on objective prism plates. The authors determined the continuum brightness at this stage to $V = 11$ mag. Duerbeck (1987) identified a candidate for the post-nova, but attempts to confirm it spectroscopically (Zwitter & Munari 1996) or by detecting the nova shell (Downes & Duerbeck 2000) remained unsuccessful.

In our photometry we find this candidate as a blue object about 10 mag fainter than the nova at the time of its detection (Fig. 2, Table 3). The spectroscopy shows a flat continuum with strong $H\alpha$ emission, much weaker $H\beta$, as well as a couple of HeI lines (Fig. 1, Table 2). The Balmer decrement is much stronger than usual in CVs (e.g., Williams 1983). Since even after the dereddening the continuum slope is not particularly steep (Table 5), it does not appear that either of the underlying stellar components of the binary is affecting the strength of the emission lines. Rather it seems more likely that an additional, non-stellar, source is contributing to the $H\alpha$ emission. Although Downes & Duerbeck (2000) did not detect a nova shell, such a shell still represents the most promising candidate for the additional $H\alpha$ source.

This is also the youngest nova in our sample, although three other systems with “normal” values are not far behind (Table 5). Ringwald, Naylor, & Mukai (1996) found that the contribution by the nebula does not only depend on the time that has passed since the eruption, but also on the speed class, with the nebular contribution being more important for slower novae. Unfortunately there is no corresponding information available for V812 Cen, and we can thus only speculate that this nova has not been a particularly fast one. A similar, even slightly stronger, Balmer decrement was found by Ringwald et al. (1996) for FH Ser ($t_3 = 62$ d) in a spectrum taken 20 years after the eruption.

3.3 V655 CrA = Nova CrA 1967

Similar to V812 Cen, this nova was discovered some time after its original eruption on objective prism plates (Sanduleak 1969). The author determined the magnitude at the time of the discovery to 13 mag. Based on the characteristics of the spectrum he estimated the

maximum brightness to 8 mag. He furthermore identifies a likely progenitor with a red magnitude of 17 mag, a value that was later corrected to $J = 17.6$ mag by Duerbeck (1987). However, the pre-nova candidate turned out to be a close visual binary, and the correct identification remained unclear. Duerbeck & Seitter (1987) took a spectrum, but it was of too low quality to even unambiguously detect the presence of emission lines. Finally, Woudt & Warner (2003) identified a likely candidate with a mean magnitude of $V = 17.6$ based on flickering-type variability detected in their high-speed photometry.

Our spectrum (Fig. 1) confirms this object as the post-nova. It shows a steep blue continuum with comparatively narrow emission of $H\alpha$ and $H\beta$, as well as a broader Bowen/HeII 4686 component (Table 2). This system likely still sustains a high mass-transfer rate.

3.4 IL Nor = Nova Nor 1893

This is the second oldest nova in this sample. It was discovered by M. Fleming on objective prism plates (as reported by Pickering 1893a). Investigations of earlier photographic plates yielded a maximum magnitude of 7 (Pickering 1893b). Duerbeck (1987) classifies it as a moderately fast nova. The post nova is a member of a close visual triple system that for some time could not be resolved, although Duerbeck & Seitter (1987) reported a spectrum showing Balmer emission lines. An attempt by Gill & O’Brien (1998) to image the nova shell was unsuccessful. In a recent paper, Woudt & Warner (2010) identified the post-nova in their high-speed photometry. The authors present two short light curves about one year apart (March 2003 and February 2004). Apart from some shorter term variability the second run showed the object on average 0.5 mag fainter than the first one.

Our photometry (Table 3, Fig. 2) reveals this candidate as a very blue object with $V = 19.0$ mag, at the same brightness as in the second photometric run presented by Woudt & Warner (2010). The spectrum consists of a blue continuum, with only weak Balmer and HeI emission. A Bowen/HeII component is also clearly visible. These characteristics suggest that more than a hundred years after its eruption this system still drives a comparatively high mass-transfer rate, which is in agreement with the results by Ringwald et al. (1996) that generally the spectroscopic properties of novae after the initial decline phase (20–30 yr) change very little over the next decades.

3.5 V2109 Oph = Nova Oph 1969

Another late discovery, this nova was reported eight years after its eruption when MacConnell (1977) detected an object with a red magnitude of 10.8 and an emission line spectrum on archival objective prism plates. A later study on Sonneberg plates by Wenzel (1992) revealed that the discovery plate missed maximum brightness by at least twelve days, when the object presented a blue magnitude of 8.9. Duerbeck (1987) identified a likely candidate for the post-nova, that was later observed by Szkody (1994) as a comparatively red star with $V = 19.4$ mag, $B - V > 1.4$ and $V - R = 1.2$.

Our spectroscopy finds the object at $R \sim 19.7$ mag, and thus much fainter than during the Szkody (1994) observations that took place 20 years after the eruption ($R = 18.2$ mag). The spectrum shows the red continuum that could be expected from Szkody’s photometry. Like in the case of MT Cen (Sec. 3.1) this is in large part due to the increased extinction in this area of the sky (Table 4). Correcting for this effect yields a considerably bluer spectrum

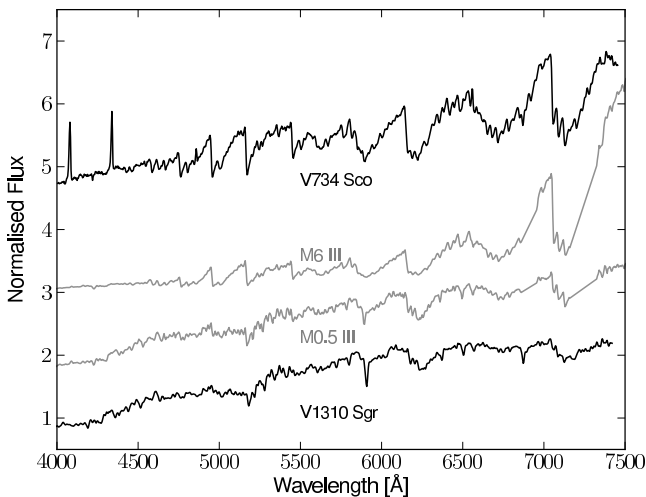


Figure 4. Spectra of the two suspected Mira stars, V1310 Sgr and V734 Sco. The data have been dereddened as described in Sec. 3.1. For comparison, two spectra from the Silva & Cornell (1992) catalogue are overplotted (light grey). Note that the wavelength regions of atmospheric absorption, 6865–6950 Å and 7165–7320 Å, in the latter data are undefined, and in the plot linearly interpolated.

(Fig. 3), although the SED is still rather unusual for a post-nova (see discussion in Sec. 4). We furthermore find moderately strong emission lines of the Balmer and HeI series, as well as HeII 4686 (Fig. 1, Table 2). Contrary to most of the other systems in this sample, the Bowen blend cannot be detected in V2109 Oph, indicating a comparatively low mass-transfer rate.

3.6 V909 Sgr = Nova Sgr 1941

Duerbeck (1987) summarises the discovery history of this nova that erupted in 1941, reached a photographic maximum brightness of 6.8 mag, and showed a very fast decline rate of $t_3 = 7$ d. Diaz & Bruch (1997) report the post-nova as being an eclipsing system with an orbital period of 3.36 h, but emphasise the need for confirmation. Since they do not provide a finding chart, the correct identification of the post-nova remained ambiguous.

In our colour-colour diagram (Fig. 2) we detect a blue object very close to the coordinates listed in the Downes et al. (2005) catalogue. The spectroscopy shows a blue continuum superposed with hydrogen and helium emission lines (Fig. 1). Certainly the most remarkable feature is the strength of HeII in the system, evidenced in the presence of the $\lambda 5412$ Å line, and the $\lambda 4686$ Å line rivalling H α in strength, while the Bowen blend appears absent (Table 2). The spectrum – at least at the current resolution and S/N – bears a strong resemblance to that of the old nova and asynchronous polar V1500 Cyg (e.g., Ringwald et al. 1996), whose 3.35 h orbital period (Patterson 1979; Semeniuk, Olech, & Nalezyty 1995) coincidentally is very close to the one reported by Diaz & Bruch (1997) for V909 Sgr.

3.7 V1310 Sgr = Nova Sgr 1935

This star was flagged as a nova by A. D. Fokker in 1951 (as reported by Duerbeck 1987) based on photometric variability. Duerbeck classifies it as a slow nova with a “steep rise and [an] extremely slow, fairly smooth decline”. The time to drop by 3 magnitudes from the photographic maximum brightness of 11.7 mag

was measured as $t_3 = 390$ d. There is no spectroscopic information available, neither near maximum brightness, nor at minimum. Downes et al. (2005) mark a fairly bright star (the 2MASS catalogue gives $R = 13.2$ mag; Cutri et al. 2003) as the post-nova, but remark that the object is possibly a Mira variable instead of a nova.

Our spectroscopy finds the star at $R \sim 13.5$ mag. The spectrum (Fig. 4) looks like a late K or early M star. No emission lines are observed. We used the TiO5 index defined and calibrated by Reid, Hawley, & Gizis (1995) to calculate a spectral type of $M0 \pm 0.5$. This is probably a Mira type star.

This poses the question if V1310 Sgr has to be qualified as a misidentification (i.e. the post-nova is some other object in the field) or as a misclassification (i.e. the original discovery report mistook the Mira variability for a nova eruption). Since both the shape and the time scale of the photometric variability as well as the observed difference in magnitude (~ 2.5 mag) are consistent with a Mira type light curve (e.g., Lebzelter 2011), we favour the latter possibility, and suggest to remove V1310 Sgr from the list of potential classical novae.

3.8 V2572 Sgr = Nova Sgr 1969

The nova was discovered due to its photometric variability that reached a maximum photographic brightness of 6.5 mag as reported by Bateson (1969). Duerbeck (1987) classifies it as a moderately fast nova with $t_3 = 44$ d. The eruption light curve is given by Knight (1972), who furthermore reports a “fairly constant” brightness of $V \sim 13$ mag for the pre-nova in the years 1957–1968, as well as for the post-nova in 1970–1972. Consistent with these findings, Radiman & Hidajat (1975) present $V \sim 12.5 \pm 0.5$ mag for the pre-nova in the years 1966–1967. However, in the same time range the authors also find an unusually red and strongly variable colour for this object to $B-V = 0.8-2.0$ mag. Since modern finding charts (Downes et al. 2005) show a fairly crowded region of the sky at the given position, it is thus likely that above values for the pre- and post-nova do not represent the nova itself, but rather the combined brightness of the nova and its close visual companions.

Supporting this interpretation we find the nova to have a steep blue continuum, and a much fainter brightness than reported of $R \sim 17.8$ mag. Emission lines of the Balmer and HeI series are clearly discernible, albeit comparatively weak. A Bowen/HeII component is also present. Overall, the spectroscopic characteristics give the impression of a high mass-transfer system. On our acquisition frame (Fig. A2) we note that the vicinity of the post-nova appears “smudgy”, which could indicate the presence of a nova shell.

3.9 V728 Sco = Nova Sco 1862 = Nova Ara 1862

Close to the border between constellations Scorpius and Ara (which is why it was originally assigned to the latter) a bright star of 5th magnitude was reported by Tebbutt (1878) to have been observed visually on October 5–9, 1862. Only four days later he found it to have declined to below 11th mag. Duerbeck (1987) identified two faint candidates ($j \sim 20-21$ mag) for the post-nova based on Tebbutt’s coordinates. Diaz & Steiner (1991) list the object as a potential magnetic nova due to its high eruption amplitude and fast decline. However, Schmidtobreick et al. (2002) note that this candidate presents colours that are more consistent with a main-sequence star than a CV. Based on their colour-colour diagram they instead suggest two new candidates that are within 1’ of the original coordinates.

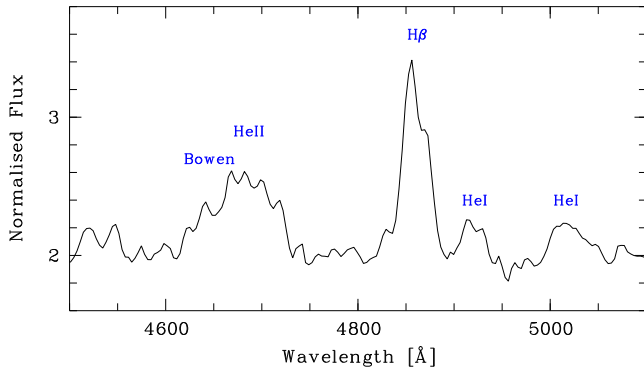


Figure 5. Close-up of the spectrum of V728 Sco. The data have been smoothed by a 3×3 box filter.

Our present photometric observations cover a larger area on the sky. The corresponding colour-colour diagram is presented in Fig. 2. The two candidates from Schmidtobreick et al. (2002) can be found as the bluest object in the field with $U - B = -0.88$, $B - V = 0.02$, and as the black square at $U - B = 0.38$, $B - V = 0.24$. Spectroscopic observations of the latter, which are not presented here in detail, showed it to be a blue star with Balmer absorption lines. The other candidate has not been observed spectroscopically. Instead we find the post-nova to be an object slightly more than $2'$ northwest of the position given in the Downes et al. (2005) catalogue (see Table 1 and Fig. A2 for the corrected position). The spectroscopy reveals a blue continuum and (for a nova) comparatively strong Balmer and HeI emission lines (Fig. 1, Table 2). This system is the one in our sample that looks most like a dwarf nova (e.g., Williams 1983) but for the blue slope and the presence of a broad Bowen/HeII component. The broad and structured Balmer emission lines (Fig. 5) make it an interesting object for further studies, because they suggest a high-inclination, possibly eclipsing, CV.

3.10 V734 Sco

As summarised by Duerbeck (1987) this object was reported as a possible long-period variable or nova by L. Plaut who discovered it to be brighter than 15^{th} mag for 10 days on photographic plates from 1937. The star is bright in the infrared: $J = 8.7$ mag, $H = 7.6$ mag, $K = 6.9$ mag (Cutri et al. 2003), and listed as a probable Mira variable in the Downes et al. (2005) catalogue.

Our spectrum in Fig. 4 shows TiO bands of a cool star and Balmer emission lines. The strongest emission is observed in H δ (equivalent width $W_\lambda = -37$ Å), followed by H γ ($W_\lambda = -22$ Å) and probably H β . This unusual Balmer decrement is typical for oxygen-rich (M-type) Mira stars (Castelaz et al. 2000). We used the TiO5 index defined by Reid et al. (1995) and calibrated by Cruz & Reid (2002) to calculate a spectral type of $M8.7 \pm 0.5$. The overall shape around 6830 Å indicates a giant rather than a dwarf star, consistent with a Mira classification.

Like in the case of V1310 Sgr we therefore conclude that V734 Sco is not a classical nova and should not be listed as such.

4 DISCUSSION

While the present work is mainly aimed at increasing the sample of confirmed old novae for later studies, and the data quality is mostly

not suited for a thorough analysis, it still allows to remark on one or the other detail.

In Table 5 we list several photometric and spectroscopic properties of the confirmed post-novae. We have used the previously reported maximum brightness m_{max} (in column 2) and the current brightness as derived from our observations m_{min} (column 3) to derive the eruption amplitude $\Delta m = m_{\text{max}} - m_{\text{min}}$ (column 4). This calculation ignores brightness differences between filters. Taking into account that the listed magnitudes are close to the visual range, and that colour differences within the $B - R$ range rarely exceed 1.0 mag (see Table 3), we can estimate a typical uncertainty of ~ 0.5 mag. Column 5 presents the “age” of the post-nova, i.e. the time that has passed from the eruption to the current observations, and column 6 summarises the time t_3 in which the nova has declined by 3 magnitudes as taken from Duerbeck (1987).

In order to examine the SED of the confirmed novae, we have fitted a power law $F \propto \lambda^{-\alpha}$ to the continuum of the dereddened spectra. We restricted the fit to wavelengths $5000 - 7200$ Å because the continuum bluewards of 5000 Å in many systems is less well defined due to the presence of several emission lines, and also the noise in general increases towards the blue end of the spectrum. The such derived values for the power-law exponent are given in column 7 of Table 5. Note that the corresponding uncertainty listed there corresponds to the standard deviation of the fit, and does not take into account additional uncertainties concerning the instrumental response function and the dereddening process. Finally, in column 8 we list the Full Width at Half Maximum of a Gaussian fit to the H β line. We have used this line instead of the stronger and usually better defined H α line in order to avoid potential contamination of the shell material.

Starting with the SED, we find that α for most systems falls well below the value of 2.33 for a steady-state accretion disc (Lynden-Bell 1969). This is in agreement with Wade (1988) who places nova-like CVs in this range, but differs from the results of Ringwald et al. (1996) who derive an average value of $\alpha = 2.68$ with a standard deviation of 0.82 for their sample of dereddened post-novae. Within our sample, MT Cen stands out by presenting with $\alpha = 4.45$ by far the largest value. In principle this could mean that this system is dominated by a still hot dwarf, but considering that it was observed 78 years after the eruption, this appears unlikely. We furthermore note that the largest correction for interstellar extinction had to be used for MT Cen. This might be coincidental, but there is also the possibility that the uncertainties in the dereddening process are the reason behind MT Cen’s exalted position, and perhaps also behind the difference between our results and Ringwald et al. (1996). Another system with an SED significantly different from the others in our sample is V2109 Oph, whose continuum cannot be fitted by a single power-law, but instead follows different laws for the range redwards of 5900 Å ($\alpha = 1.82$) and for the range $5000 - 5900$ Å ($\alpha = -0.21$). A similar phenomenon has been observed by Schmidtobreick et al. (2005) for the old novae V630 Sgr and V842 Cen, of which the former is more similar to our case, since it also presents the less steep continuum slope for the blue part of its SED. The authors interpret their findings as the signature of a disrupted inner accretion disc, and, encouraged by the strong HeII emission in the system, suggest that V630 Sgr is a magnetic CV. In V2109 Oph, however, the HeII line is not particularly strong for an old nova, and with the present data there is no reason to suspect magnetic accretion. Instead, Fig. 3 shows that the continuum slope bluewards of 5000 Å again increases and appears similar to that redwards of 5900 Å. Such “bumpy” continuum could in principle be the signature of an SED that is dominated by

Table 5. Properties of the confirmed post-novae. See text for details.

object	m_{\max}^1 [mag]	m_{\min} [mag]	Δm [mag]	Δt [yr]	t_3 [d]	α	$FWHM(H\beta)$ [Å]
MT Cen	8.4 <i>p</i>	19.8 <i>V</i>	11.4	78	~ 10	4.45(07)	14
V812 Cen	<11.0 <i>V</i>	21.3 <i>V</i>	>10.3	36	–	1.75(11)	16
V655 CrA	8.0 <i>p</i>	17.7 <i>R</i>	9.7	42	–	1.44(02)	10
IL Nor	7.0 <i>p</i>	19.0 <i>V</i>	12.0	116	108	2.53(03)	21
V2109 Oph	8.9 <i>b</i>	19.7 <i>R</i>	10.8	40	–	−0.21(03) / 1.82(08) ²	13
V909 Sgr	6.8 <i>p</i>	20.4 <i>V</i>	13.6	68	7	1.41(04)	20
V2572 Sgr	6.5 <i>p</i>	17.8 <i>R</i>	11.3	40	44	2.19(02)	16
V728 Sco	5.0 <i>v</i>	18.5 <i>V</i>	13.5	147	<9	1.85(03)	30

1) *p*: photographic, *V*: V-band, *b*: blue, *v*: visual2) first value for $\lambda < 5900$ Å, second value for $\lambda \geq 5900$ Å

the stellar components instead of the accretion disc. Further evidence for this, e.g. in the form of stellar absorption lines, however is missing. Without further data it therefore remains unclear if the shape of the continuum in V2109 Oph is intrinsic or an artifact due to a problem in the extraction or dereddening process.

Looking at the eruption amplitudes we find that two systems, V909 Sgr and V728 Sco, match the criterion of Schmidtobreick et al. (2004) for a Tremendous Outburst Nova (TON), $\Delta m > 13$ mag. Based on the assumption that the absolute eruption magnitude is very similar for all novae the authors (see also Schmidtobreick et al. 2005) suggest that a large eruption amplitude indicates a faint post-nova, either because it is seen at high inclination (Warner 1987), or because it is intrinsically faint due to a low mass-transfer rate. V728 Sco could fit into the former category. It is the only system in our sample whose emission lines are broad enough to be well-resolved (last column in Table 5), and additionally these lines show a distinctive structure (Fig. 5). Following Diaz & Steiner (1991) a large eruption amplitude and a fast decline can also indicate a magnetic nova, since discless systems, or those with a disrupted disc, should be intrinsically fainter than disc CVs. Since V909 Sgr additionally presents a particularly strong HeII emission, it is a good candidate for this category.

5 SUMMARY

We have conducted a study on ten candidate old novae. Among them we have found two probable Mira stars whose variability likely was confused with a nova eruption, and we propose to delete these stars, V1310 Sgr and V734 Sco, from the list of potential novae. We have furthermore spectroscopically confirmed seven previously selected candidate post-novae, as well as recovered one system, V728 Sco, that was found to be $\sim 2'$ away from the reported coordinates.

Within the confirmed old novae we find a group of four objects that – after correction for interstellar reddening – share very similar spectral properties: MT Cen, V655 CrA, IL Nor, and V2572 Sgr, all have the blue continuum and the weak emission lines that are typical for high mass-transfer systems. The remaining four novae instead present at least one peculiarity that distinguishes them from the other systems in our sample. V2109 Oph presents a “bumpy” continuum for which with the current data we do not find an explanation, and V909 Sgr shows several trademarks of a magnetic systems. V812 Cen has an unusually strong Balmer decrement, and one can assume that the ejected material still contributes to the H α emission. Last, not least, V728 Sco is the only system in our

sample where we find convincing evidence that it has a comparatively high inclination, and it should therefore be possible to derive its orbital period with time-series photometry.

ACKNOWLEDGMENTS

In fond memory of Hilmar W. Duerbeck (1948–2012)

We would like to thank the referee, Mike Shara, for giving us the thumbs up.

This research was supported by FONDECYT Regular grant 1120338 (CT and NV). AE acknowledges support by the Spanish Plan Nacional de Astronomía y Astrofísica under grant AYA2011-29517-C03-01. REM acknowledges support by the Chilean Center for Astrophysics FONDAF 15010003 and from the BASAL Centro de Astrofísica y Tecnologías Afines (CATA) PFB–06/2007.

We gratefully acknowledge ample use of the SIMBAD database, operated at CDS, Strasbourg, France, and of NASA’s Astrophysics Data System Bibliographic Services. The Digitized Sky Surveys were produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166, based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain and the UK Schmidt Telescope. We have furthermore made use of the NASA/ IPAC Infrared Science Archive, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. IRAF is distributed by the National Optical Astronomy Observatories.

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APPENDIX A: FINDING CHARTS

Here we present finding charts for the eight confirmed old novae. Where available the combined EFOSC2 *R* band photometric images were used, otherwise the EFOSC2 acquisition frames were employed. The two discarded nova candidates, V1310 Sgr and V734 Sco, can be unambiguously identified on finding charts in the Downes et al. (2005) catalogue.

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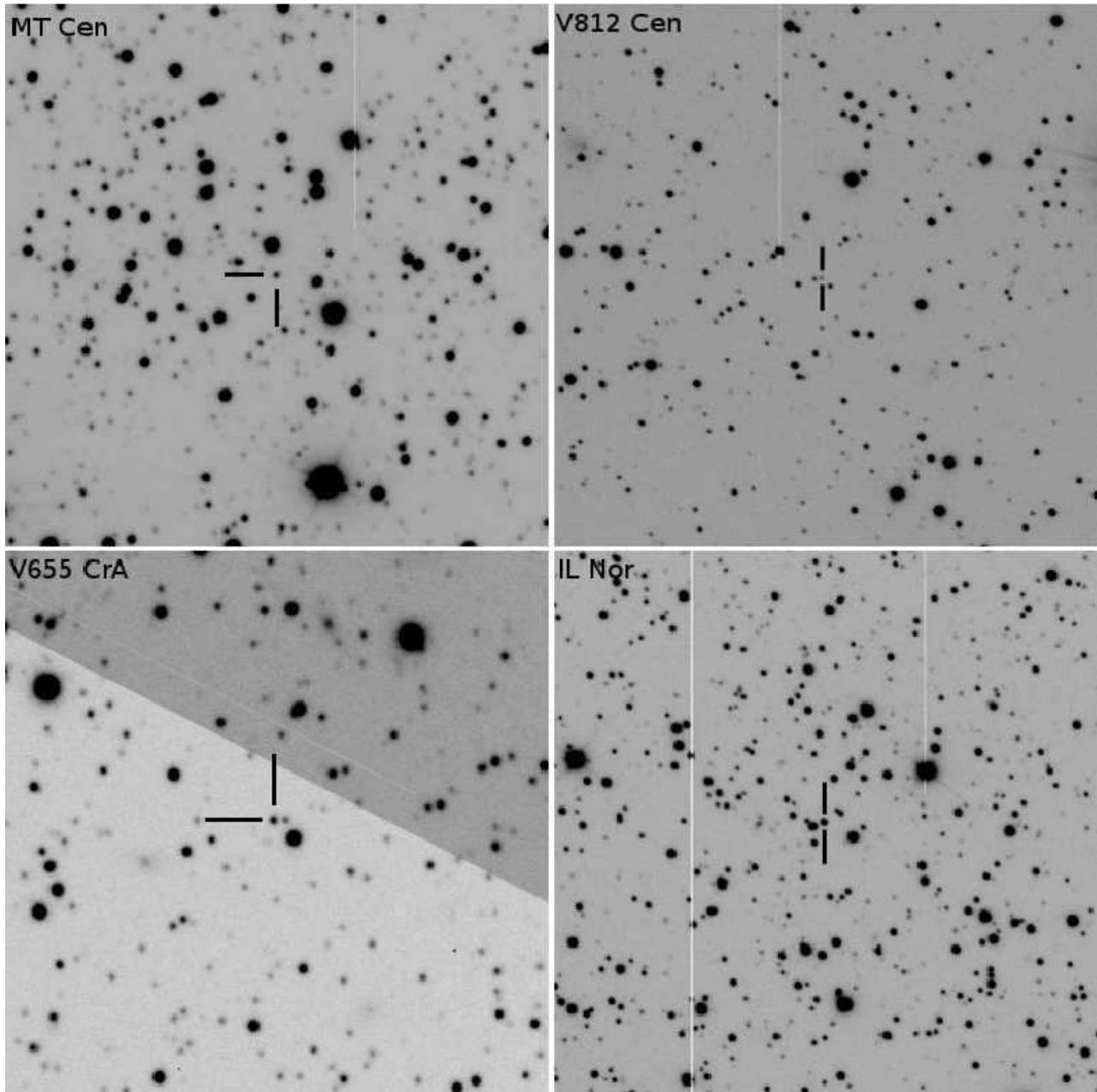


Figure A1. Finding charts for the confirmed old novae MT Cen, V812 Cen, V655 CrA, and IL Nor. The size of a chart is $1.5' \times 1.5'$, and the orientation is such that North is up and East is to the left. The images were taken in the R band.

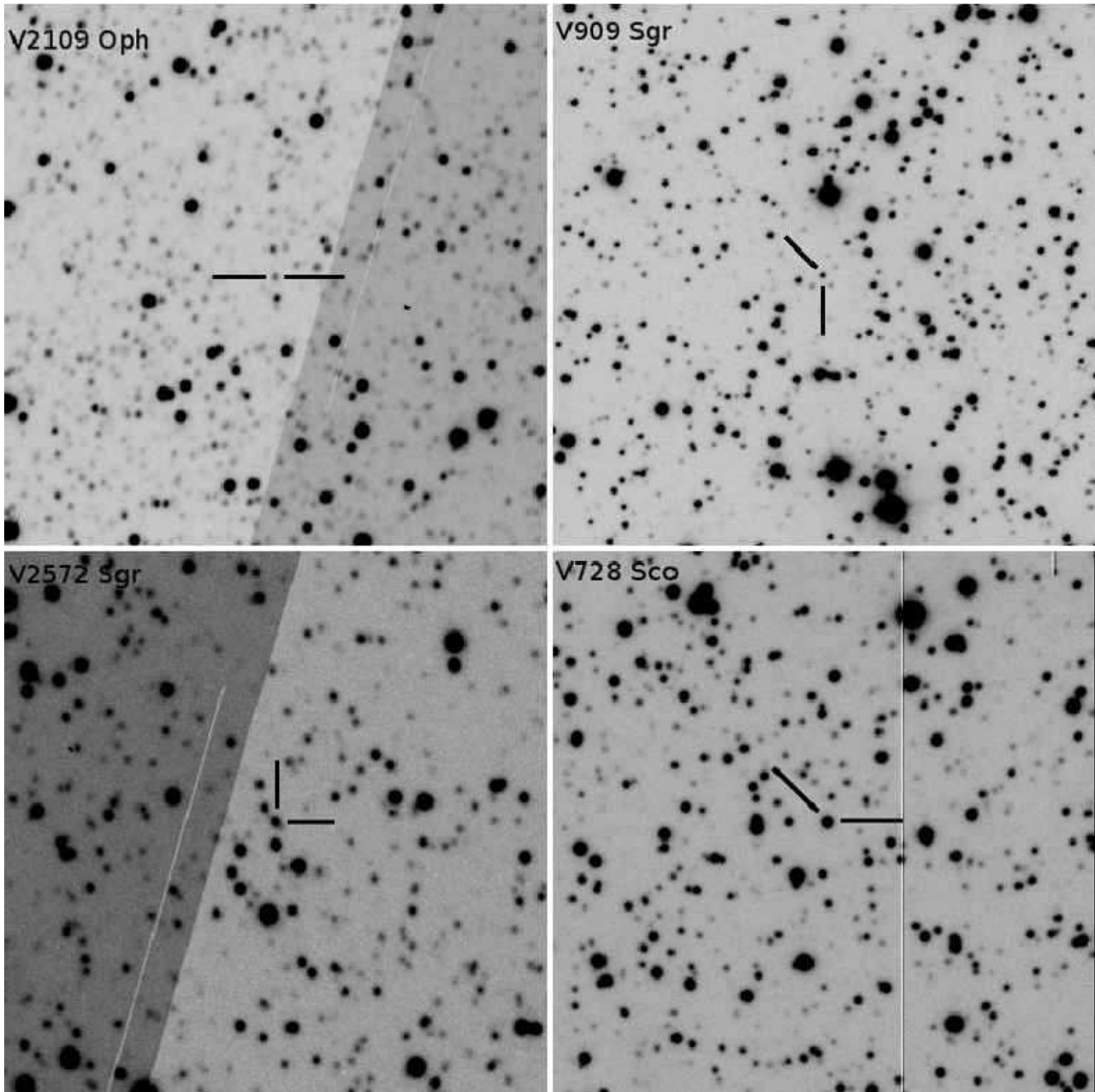


Figure A2. Finding charts for the confirmed old novae V2109 Oph, V909 Sgr, V2572 Sgr, and V728 Sco. The size of a chart is $1.5' \times 1.5'$, and the orientation is such that North is up and East is to the left. The images were taken in the R band.